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WADC TECHNICAL REPORT 55-356

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EFFECT OF WATER CONTENT AND COMPRESSION ON THERMAL INSULATION OF CLOTHING

JOHN F. HALL, JR.
JOHANNES W. POLTE

AERO MEDICAL LABORATORY

OCTOBER 1955

WRIGHT AIR DEVELOPMENT CENTER

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JOHN F. HALL, JR.
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OCTOBER 1955

PROJECT No. 7155
TASK No. 71804

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
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FOREWORD

This report by John F. Hall, Jr. and Johannes W. Polte, initiated under Project No. 7155, "Human Thermal Tolerance," was administered under the direction of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center. The project was conducted during the period from January to July 1955 by members of the Environment Section of the Physiology Branch, and all tests were carried out in the test facility (All Weather Room) of the Aero Medical Laboratory.

ABSTRACT

The effects of water compression (resulting from immersion to the neck level), simulated water leakage, and sweat accumulation upon thermal insulation of a typical Air Force protective clothing assembly were determined in a series of 55 experiments conducted with a copper manikin. Results of a series of tests on the effect of simulated sweat on thermal insulation of footwear (sock) are also included.

Insulation loss due to hydrostatic compression and removal of the ambient air insulation (Ia) was significant, amounting to 56.8%; addition of water in quantities ranging from 100 to 1000 gm/m^2 caused further reduction of thermal insulation, reaching a total of 77.6% at 1000 gm/m^2. Percentage loss of thermal insulation with increasing water content whether simulating leakage (measurements in water) or sweat accumulation (measurements in air) was similar. Comparable effects of water upon the thermal insulation of footwear were also observed in a series of 12 tests conducted on a copper thermal foot. On the basis of a total body heat storage loss of 50 Cal/m^2/hr, predictive curves for human tolerance time in water of 0°C as functions of clothing water content, metabolic level, and thermal insulation are presented. Measured heat loss of the clothed manikin in water was 2.3 to 4.0 times greater than in air, depending upon whether clothing was dry or maximally wetted (1000 gm/m^2).

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

Modern long-range aircraft missions over arctic seas or terrain require clothing suitable for the protection of aircraft crew members against the hazards of emergency exposure to extremely cold water. The serious and often fatal hypothermia resulting from such exposures was indicated by the work of Spealman,[9] Newburgh and Spealman,[6,7,8] Molnar,[5] and Wayburn[11]. Newburgh and Spealman emphasized the protective value of water-impermeable type suits and their usefulness in protecting against cold water immersion, or exposure of personnel to cold wind while on life rafts is now clearly recognized. Both the Air Force and Navy presently have water-impermeable anti-exposure suits for protection against cold water immersion exposures.

Emergency exposure of aircraft crew members to extremely cold water, however, may occur under conditions where individuals wearing such impermeable suits have accumulated considerable amounts of sweat within their clothing. Furthermore, accidental leakage of the cold water during the immersion period may occur. In both cases (i.e., sweat or water leakage) the net effect is similar, namely a reduction of the thermal insulation with a consequent decrease of safe tolerance or exposure time. Although information exists as to relative heat loss of man in air and water,[5] quantitative data concerning the effect of (1) water compression and (2) clothing water content on thermal insulation are scarce. Griffin, et al.[2] reported a decrease in thermal insulation when sweat or small amounts of water were added to clothing, but the studies reported by these investigators did not include water immersion.

The present studies were undertaken to quantitatively determine: (1) the effect of water compression on thermal insulation; (2) the relation between clothing water content and thermal insulation when measured in either air or water; (3) the effect of wetting small body areas (foot) as compared with large areas (trunk, arms, legs); and (4) the relative heat loss of a clothed manikin in air and water when wearing dry or wetted clothing. Data derived from the reported results has permitted the calculation of predicted tolerance times in water at 0°C (and other temperatures) as a function of the clothing insulation or water content at various metabolic levels. This type of information is required for the formulation of realistic survival or rescue times for air crew members exposed by emergency to cold water immersion.

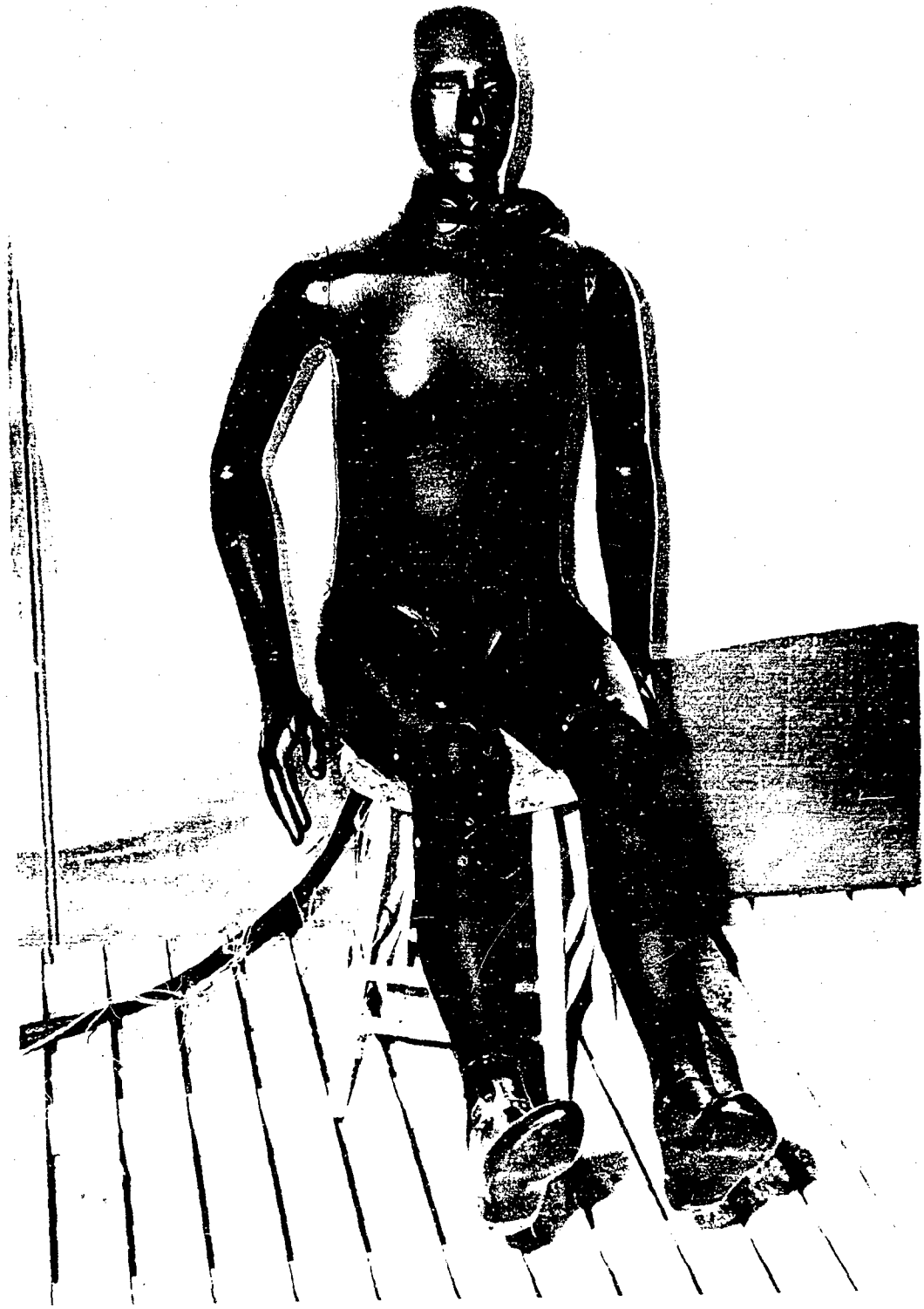


Figure 1. Nude Copper Manikin - Position for Air Insulation (I_a) Measurements.

PROCEDURE

Thermal insulation of complete clothing assemblies was measured with a sitting model copper manikin (fig. 1) and insulation of the footwear (sock) by means of a copper thermal foot. Sixty-seven experiments were conducted, including 12 in connection with the wet sock study. Thermal insulation was measured and is expressed in terms of clo* units.

The various clothing items composing the measured clothing assemblies are illustrated in figures 2-7 and are listed in table 1. In figure 1 the position of the nude manikin is shown in the position used for measurements of the insulation of the ambient air (I_a) and of the dry and wet clothing in air. Figure 8 shows the position of the fully dressed manikin in water; this is typical of the immersion depth used in all the water measurements of insulation. Water temperature (13°-18°C) was continuously measured with copper-constantan thermocouples and recorded on a Leed and Northrop Micromax. Variation in water temperature did not exceed ±0.5°C in any one test, and the water was constantly stirred by means of a stream of compressed air.

TABLE 1

CLOTHING COMPONENTS WORN

CLOTHING ASSEMBLY TESTS	1. Two-piece cotton-wool (50-50) underwear, medium-regular 2. USAF anti-g suit, G-4B, medium-regular 3. USAF ventilating garment, MA-1, regular 4. Insulation liner (Navy type) for Mk-IV anti-exposure suit, size 40 5. Wool knit glove inserts 6. Medium-weight wool socks 7. Bristolite (10 D) sealed insulation boots 8. USAF anti-exposure suit, type R-1 9. USAF experimental insulation liner, medium-regular
WET SOCK TESTS	10. Cushion sole sock, size 10 11. Vinylite sock, outer and inner 12. Quartermaster leather shoe, size 9 D

* The clo is a unit of insulation defined as the insulation necessary to maintain in comfort a sitting-resting subject in a normally ventilated room when air movement is 20 ft/min, ambient air temperature is 70°F and humidity is less than 50%.

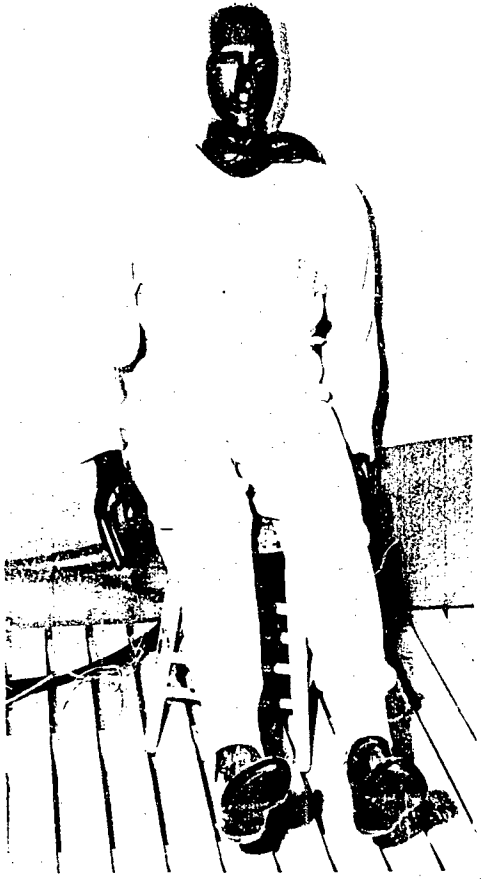


Figure 2.

Two-piece Cotton-Wool (50-50) Underwear

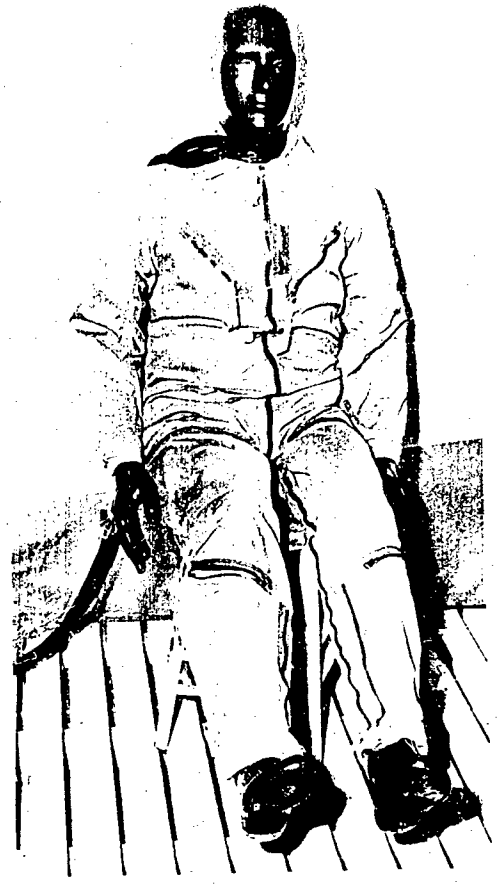


Figure 3.

USAF Anti-g Suit, G-4B

Figure 4.

USAF Ventilating Garment, MA-1, Medium-weight Wool Socks, and Wool Knit Glove Inserts

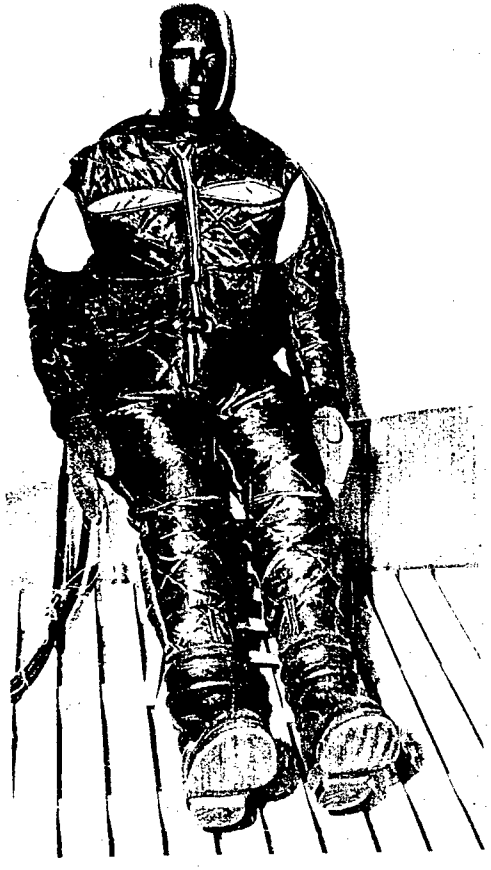


Figure 5.

Anti-exposure Suit Liner (Navy Type) and Bristolite Boots

Figure 6.

Anti-exposure Suit Liner (USAF Experimental Type)

Figure 7.

USAF Type R-1 Anti-exposure Suit

Position for Clothing Insulation Measurements in Air

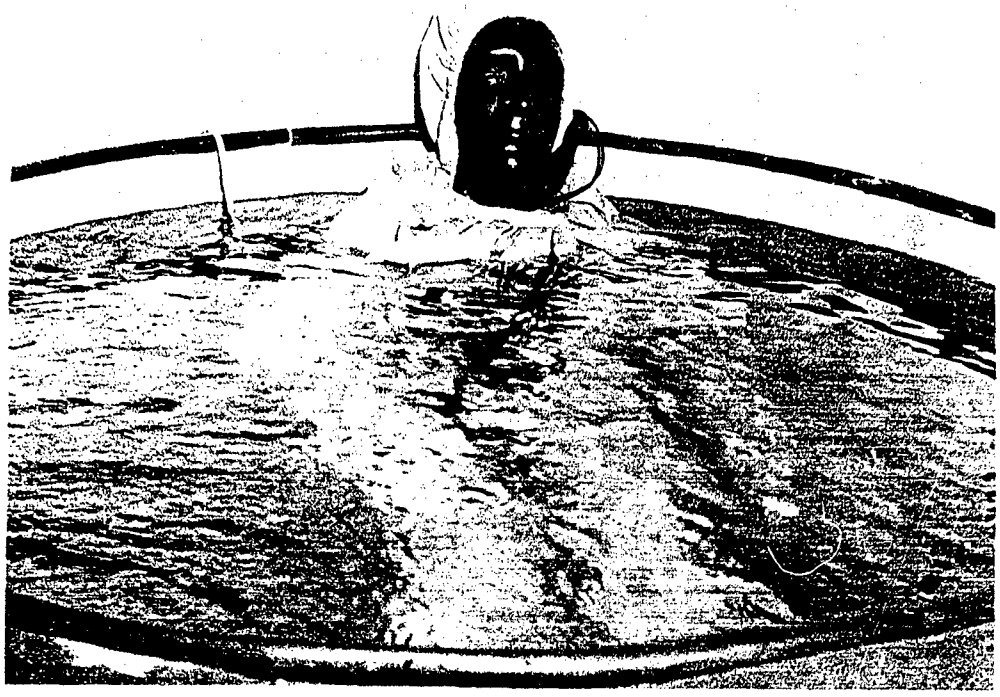


Figure 8. Manikin Position for Clothing Insulation Measurements in Water

Insulation of the Ambient Air (I_a)

Since insulation of the air layer surrounding the manikin is a component of the total or effective insulation, these measurements were required if total thermal insulation of clothing in air was to be considered. These experiments were conducted with the nude manikin, and the results were obtained under two different ambient air temperature (and consequent air movement) conditions which are presented below:

Ambient Temperature	Number of Tests	I_a - clo (average)
14°C	2	0.47
27°C	3	0.65

These values used in the air measurements of thermal insulation are reflected in the values presented in the summary of all experiments (table 2). Values for I_a, in the case of the copper thermal foot where experiments were performed in a different test room, are of course different, the average value for the nude foot (I_a) being 0.45 equivalent clo.

Air Measurements - Dry and Wet Clothing

Measurements of clothing insulation in air, and with the manikin dressed in dry clothing, were first conducted by methods previously described by Hall and Polte[3] and routinely used for copper manikin models. Measured quantities of water were added to the clothed trunk, arm and leg areas of the manikin and

the water-impermeable (R-1) outer exposure suit was then immediately placed over the wetted clothing. A specially improvised neck closure prevented loss of any significant quantity of water during the insulation test period. All clothing items were weighed before and after measurements of insulation, and water content figures are based upon amounts present at the conclusion of each test. In these air measurements, the total, or effective, thermal insulation is equivalent to the sum of garment (I_g) and air (I_a) insulations, thus $I_{effective} = I_g + I_a$. Manikin position for clothing insulation measurements in air is illustrated in figure 7.

In these tests the outer clothing worn was impermeable since this was required in the water tests to prevent leakage. The relative impermeability of the outer clothing to air practically eliminated air permeability as a factor in the measurement of the clothing insulation in air. Air movement was also relatively low, being less than 200 ft/min in all tests of this type.

Water Measurements - Dry and Wet Clothing

Thermal insulation of the dry clothing was measured by immersing the fully dressed manikin to the neck level in a tank of constantly stirred water. In this position approximately 92% of the total manikin area was immersed (i.e., 1.74 m^2). Manikin position for clothing insulation measurements in water is shown in figure 8. Methods for adding water, test procedure, and method in general for the water measurements were similar to those for the air measurements. However, in water total, or effective, insulation due to removal of the ambient air insulation (I_a) is represented by only garment insulation (I_g); thus I (effective insulation) equals I_g.

Wet Sock Measurements in Air

The effect of wetting a relatively small body area (sock or foot, 0.07 m^2) was studied in a series of tests conducted on a thermal copper foot. In these tests a cushion sole sock was placed between two very thin water-impermeable rubber socks and this entire combination then fitted within a standard type Army issue leather shoe (12 EE) which in turn was fitted upon the copper thermal foot. Dry insulation of this footgear assembly was determined by the described method. Measured quantities of water were then added to the sock and insulation at the various degrees of wetting determined. Degree of sock wetting was varied from 10 to 90% of its saturation value.

RESULTS

Water Content and Insulation of Clothing Assemblies - Air and Water

A summary of the results of the insulation measurements of dry and wet clothing obtained in air and water is presented in table 2. Measurements of the effect of clothing water content on the insulation of complete clothing assemblies (large wetted area) were conducted with two objectives in view: (1) to simulate effects of sweating as represented by the determination of wet

clothing insulation in air; and (2) to simulate water leakage and/or sweating effects, these conditions being represented by the determination of wet clothing insulation in water. In figure 9 the effects of water content on thermal insulation (clo) of clothing are plotted. Curves for effective insulation in air ($I_g + I_a$) and in water (I_g) are given, and effects obtained with large wetted body areas compared to those observed when small areas (socks) are similarly wetted. In figure 10 the percentage loss of thermal insulation (I_g) due to water content is graphically compared for complete clothing assemblies in air and water. These curves are generally similar, coinciding closely in the range 0-500 gm/m^2. In figure 11 individual experiments have been arranged into four groups according to clothing water content and average water content for the group plotted against average percentage loss of thermal insulation. The similarity of the curves and profiles obtained for large wetted clothing areas (assemblies) in either air or water, with small wet clothing areas (socks) is shown.

Water Content and Thermal Insulation of Socks - Air

The relationship between water content and thermal insulation of small wetted body areas (socks) is illustrated in figures 9, 10, 11, and 12. In all graphs the general similarity of wetting small, as compared with large areas, in this respect, may be noted. Precision of measurement and technique for wetting the sock were more satisfactory than was the case for complete clothing assemblies and is reflected in the smoother curve obtained. In the range 0-200 gm/m^2 the curves for large and small areas agree quite well, and even in the higher water content range (200-1000 gm/m^2) differences between the two areas did not exceed 12% at any equivalent wetness. Detailed results are included in table 2.

Water Compression and Thermal Insulation

Although loss of thermal insulation in water immersion due to hudrostatic pressure is obviously to be expected, quantitative information on this factor has previously been lacking. In figure 13 the effect of both wetting and compression on thermal insulation is graphed. Comparison of the effective clothing insulation value when measured dry, in air (3.36 clo), with that when measured dry in water (1.45 clo) shows the significant loss of insulation resulting from water compression. In the same figure the effect of water compression, when an experimental USAF insulating liner (table 1, item 9; and fig. 6) was substituted for the Navy type liner (table 1, item 4; fig. 5) as a component in the complete clothing assembly, is also included. Comparative compression curves of these respective liners are illustrated in figure 14, the USAF type being slightly more resistant to compression under the lower loads. In figure 15 a percentage analysis of the losses in total, or effective insulation in air as compared with dry and equivalent wetted conditions in water is presented. Effective or total insulation in air was reduced from 3.36 to 2.26 clo by maximal wetting (940 gm/m^2) of the clothing; in water, however, the same clothing assembly, wet to approximately the same extent (1051 gm/m^2), total or effective insulation was reduced to 0.73 clo, a total loss in potential insulation of 78.6%. Insulation loss due to compression of the dry clothing was more significant, it may be observed, than loss due to water content.

TABLE 2

INSULATION MEASUREMENTS OF DRY AND WET CLOTHING IN AIR AND WATER

CLOTHING TESTED	TESTS No.	AMBIENT CONDITION	WATER CONTENT gm/m^2	THERMAL INSULATION - clo	
				$(I_g + I_a)$	(I_g)
Assembly	3	Air	0	3.36	2.71
Assembly and Exp. Liner	3	Air	0	2.83	2.18
Assembly	2	Air	181	3.27	2.62
	2	Air	207.5	2.79	2.14
	2	Air	228.7	2.07	2.42
	5	Air	312.5	2.81	2.24
	2	Air	377.3	2.53	1.87
	3	Air	403.5	2.50	1.97
	1	Air	475.9	2.77	1.12
	2	Air	518.1	2.58	2.11
	3	Air	652.3	2.46	1.99
	5	Air	764.5	2.49	2.02
	2	Air	940.2	2.26	1.79
Assembly	3	Water	0		1.45
Assembly and Exp. Liner	2	Water	0		1.11
Assembly	2	Water	98.9		1.36
	2	Water	221.8		1.24
	2	Water	337.4		1.18
	2	Water	362.1		1.05
	2	Water	436.2		1.03
	2	Water	689.7		0.94
	2	Water	1051.1		0.73
Sock	4	Air	0	1.06	0.62
Sock	2	Air	126.7	0.99	0.53
	2	Air	549.2	0.91	0.44
	2	Air	1098.6	0.86	0.37
	2	Air	1267.6	0.79	0.32

Relative Heat Loss of Clothed Manikin in Water and Air

The preceding measurements of resistance to heat flow, or insulation, of this assembly on the copper manikin in air and water with both dry and wet clothing, permitted the measurement of the relative heat loss ratio water/air. In figure 16 the relative heat loss of the clothed manikin in water and air is shown for dry and various wetted clothing conditions. This varied from 2.3 for dry conditions to 4.0 for the maximally wet clothing. The curves plotted were based upon the assumption of an equivalent initial mean skin temperature (33.3°C). As the heat loss ratio values indicate, cooling in water compared to air, increases significantly as clothing becomes wet. The calculated values of 2.3, 2.9, and 4.0 were checked by copper manikin measurements of heat loss in air versus water at equivalent temperature gradients. Mean values of these measurements (two or more tests) are also shown in figure 16. If comparisons between cooling in water and air of clothing equally wetted are made, the ratio is slightly lower as figure 16 indicates.

Predictions of Human Tolerance Time at 0°C Water Temperature

The relationship between insulation and clothing water content of this protective clothing assembly in both water and air, having been defined, a further extension of the data permits the prediction of human tolerance time in a condition of extremely cold water (0°C). These predicted tolerance time curves are based upon the following assumptions:

(1) body surface area = 1.8 m^2

(2) mean terminal skin temperature of 24°C for water exposures; 30°C for air exposures

(3) net body heat storage at start of immersion = 0 ($Cal/m^2/hr$)

(4) air or water temperature equals 0°C; in figure 20, temperatures of 6°C are also considered

(5) body heat storage limit of 50 $Cal/m^2/hr$; i.e., 90 Cal/hr for the man

(6) average metabolic heat increase, due to cold water exposure, 50%; this is included in the calculated metabolic rates.

Assumptions (2) and (6), with respect to cold water immersion, are based on previously published data[4] and with respect to air exposures assumption (2) is based upon results of Taylor[10] which indicated the above selected heat debt (5) as sufficient to bring an individual to a point of uncomfortable cold and shivering. While the limitations of some of the assumptions are clearly realized, these tolerance time predictions are presented to furnish reasonably realistic information of a type previously lacking.

In figure 17 tolerance times in water at 0°C at metabolic levels of 75, 85, and 112.5 $Cal/m^2/hr$ are plotted as functions of clothing water content.

In figure 18 tolerance time at these same metabolic levels and water temperature is plotted as a function of clothing insulation in water (Ig). In both types of graph the gain in tolerance time due to metabolic increase is significant.

In figure 19 comparison of net body heat storage changes in air and water at 0°C with both dry and wet clothing at various metabolic levels is graphically presented. The assumed heat loss tolerance limit (90 $Cal/m^2/hr$) is indicated by a dashed horizontal line on the graph. Data on this graph, it should be cautioned, apply specifically to the type protective clothing or assembly used in these measurements, or to clothing assemblies having closely similar insulation values (3.4 clo). In water, for example, with dry clothing and a metabolic level of 75 $Cal/m^2/hr$, a tolerance time of three hours is indicated. With a lower metabolic level (50 $Cal/m^2/hr$) tolerance time is reduced to 72 minutes. The marked difference between air and water tolerance times at equivalent metabolic levels, particularly if clothing is wet, is clearly shown.

In figure 20 curves are presented which predict tolerance times at different water temperatures (0°, 6°C) and at different metabolic levels as a function of clothing water content. In the upper plot comparative tolerance time in water versus air at 0°C at a metabolic level of 50 $Cal/m^2/hr$ is presented. The prediction of tolerance time has in this case been extrapolated, as indicated by the dotted line, to a limit of 500 minutes.

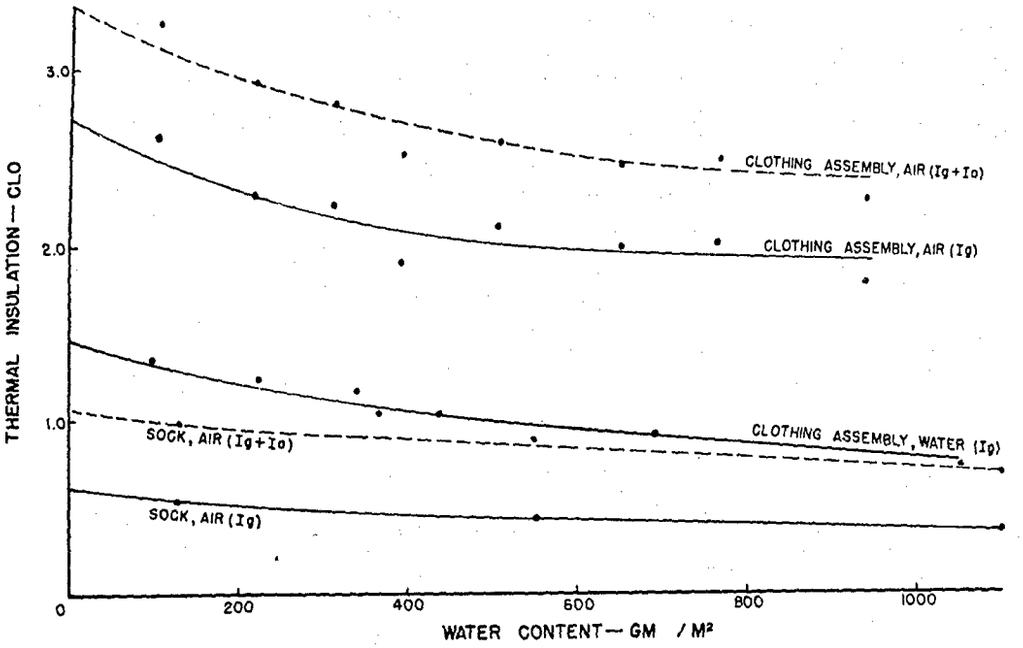


FIGURE 9 — EFFECT OF WATER CONTENT ON THERMAL INSULATION OF CLOTHING

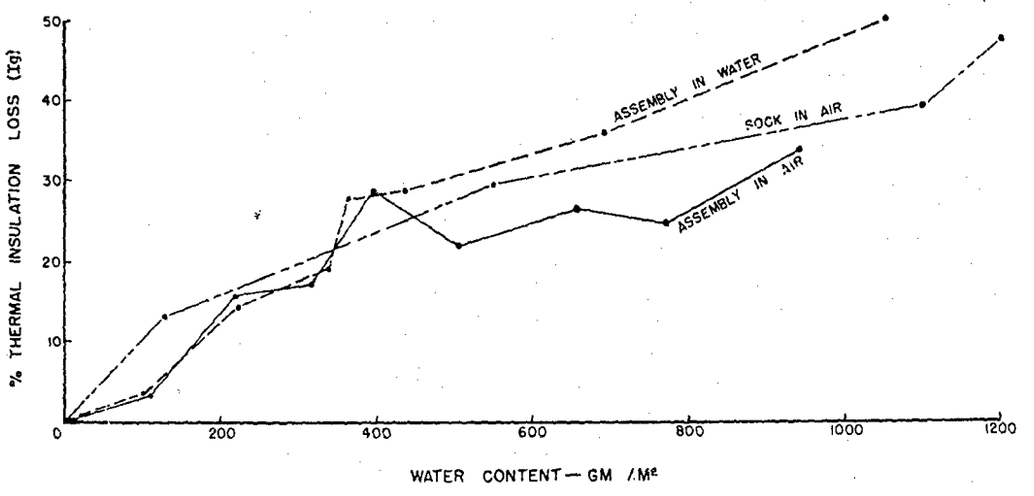


FIGURE 10 — PERCENT THERMAL INSULATION LOSS (Ig) AND WATER CONTENT OF CLOTHING

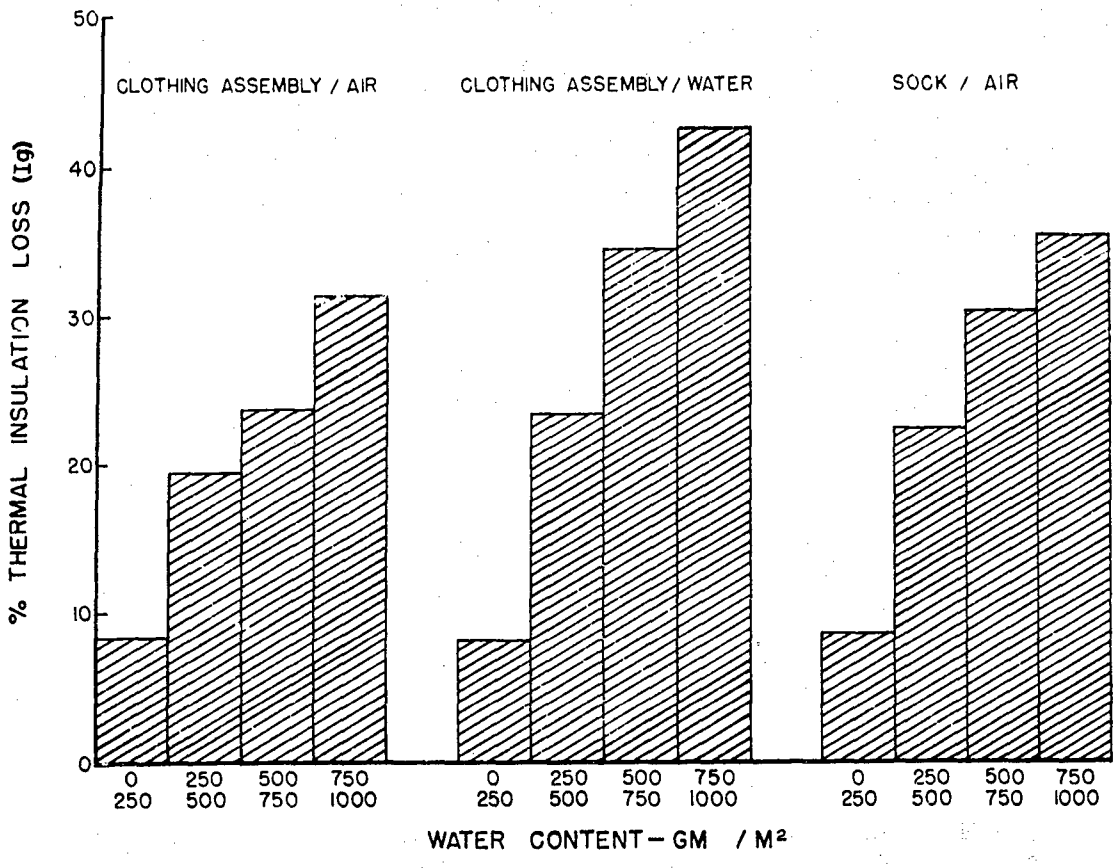


FIGURE 11 — PERCENT LOSS IN THERMAL INSULATION (Ig) OF WET CLOTHING IN AIR AND WATER

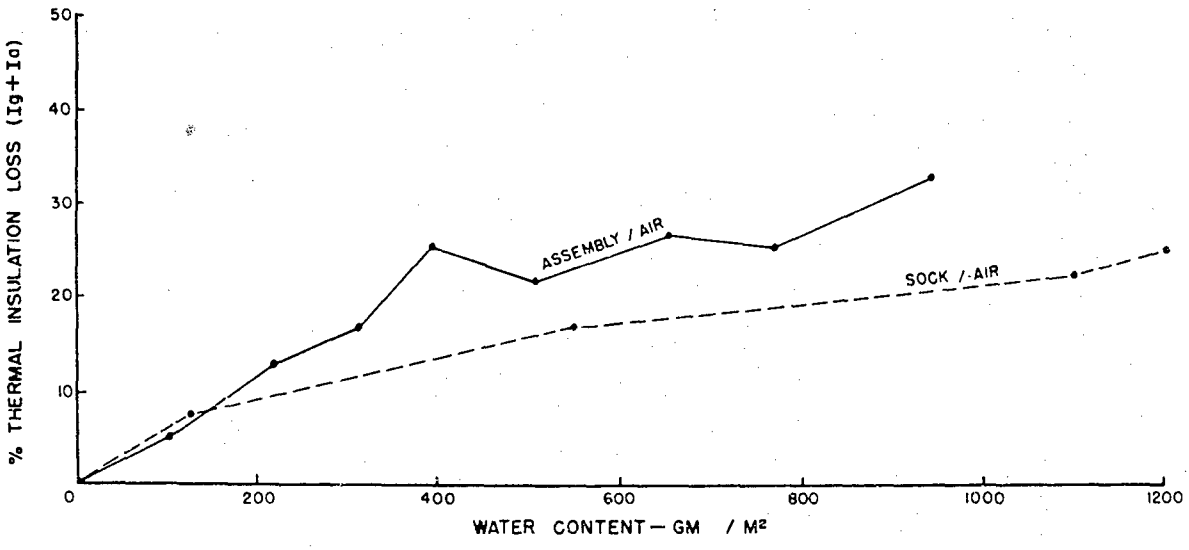


FIGURE 12 — PERCENT THERMAL INSULATION LOSS (Ig + Ia) AND WATER CONTENT OF CLOTHING

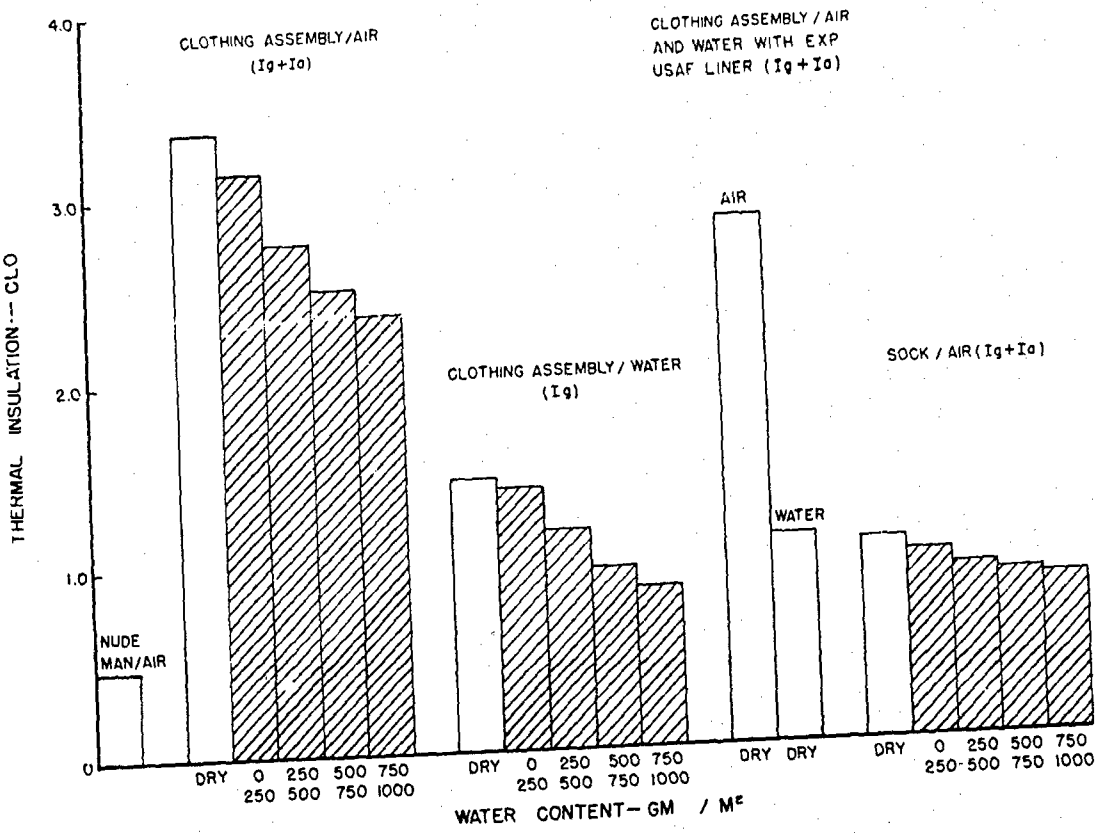


FIGURE 13 — EFFECT OF WET CLOTHING AND WATER COMPRESSION ON THERMAL INSULATION

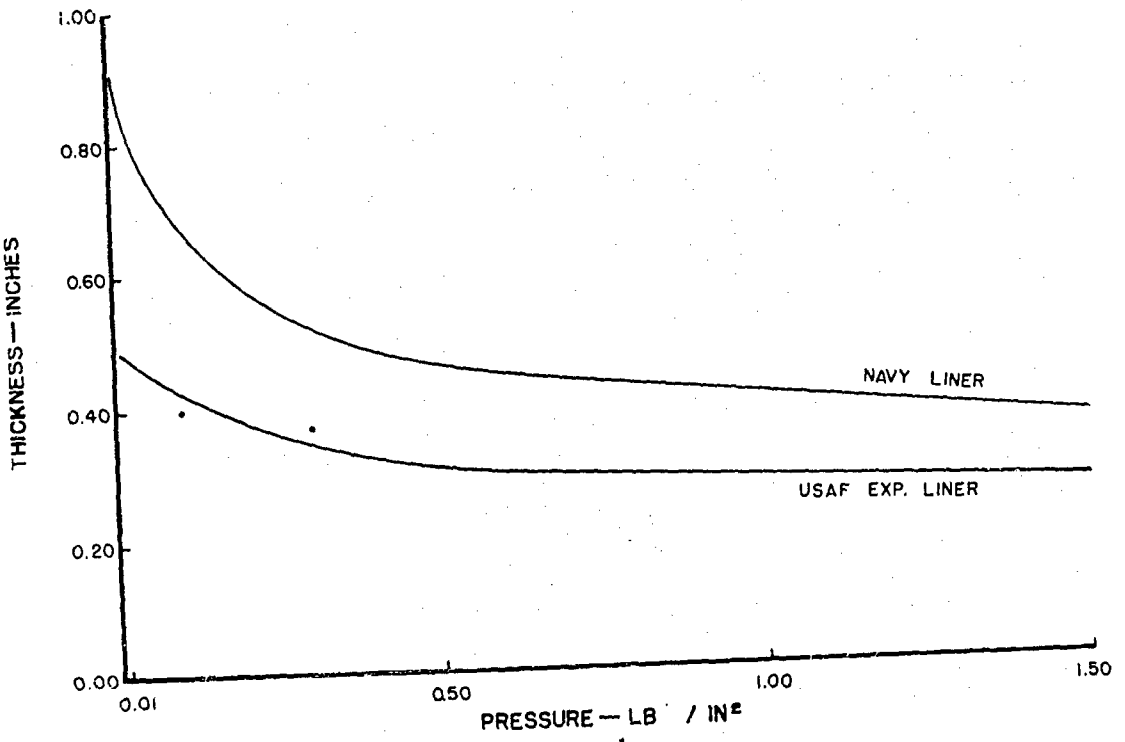


FIGURE 14 — COMPRESSION CURVES OF NAVY AND USAF EXPERIMENTAL INSULATING LINERS

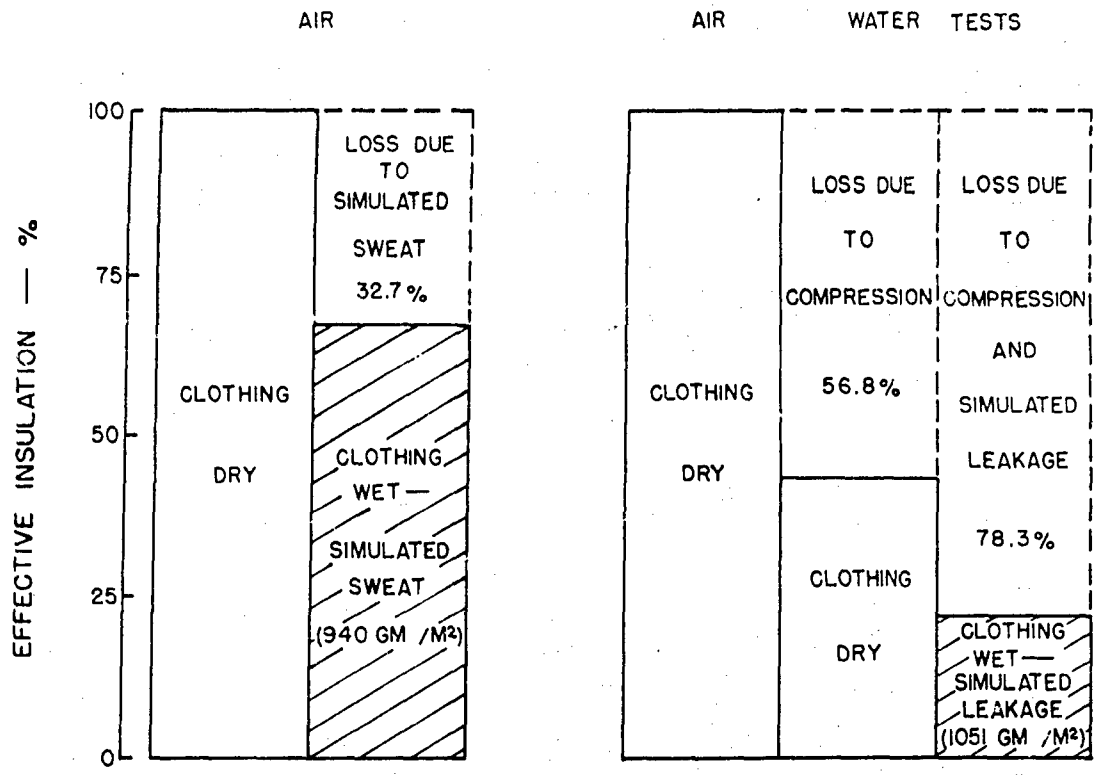


FIGURE 15 — THERMAL INSULATION LOSSES IN AIR VS WATER

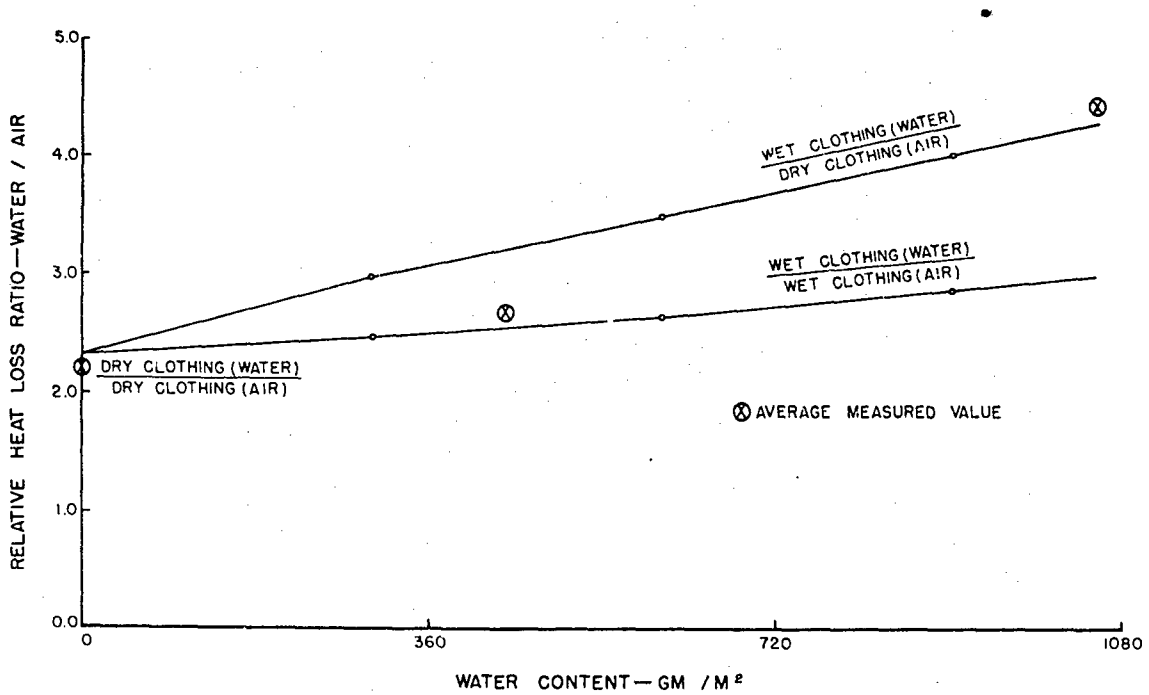


FIGURE 16 — RELATIVE HEAT LOSS OF CLOTHED COPPER MANIKIN IN WATER AND AIR

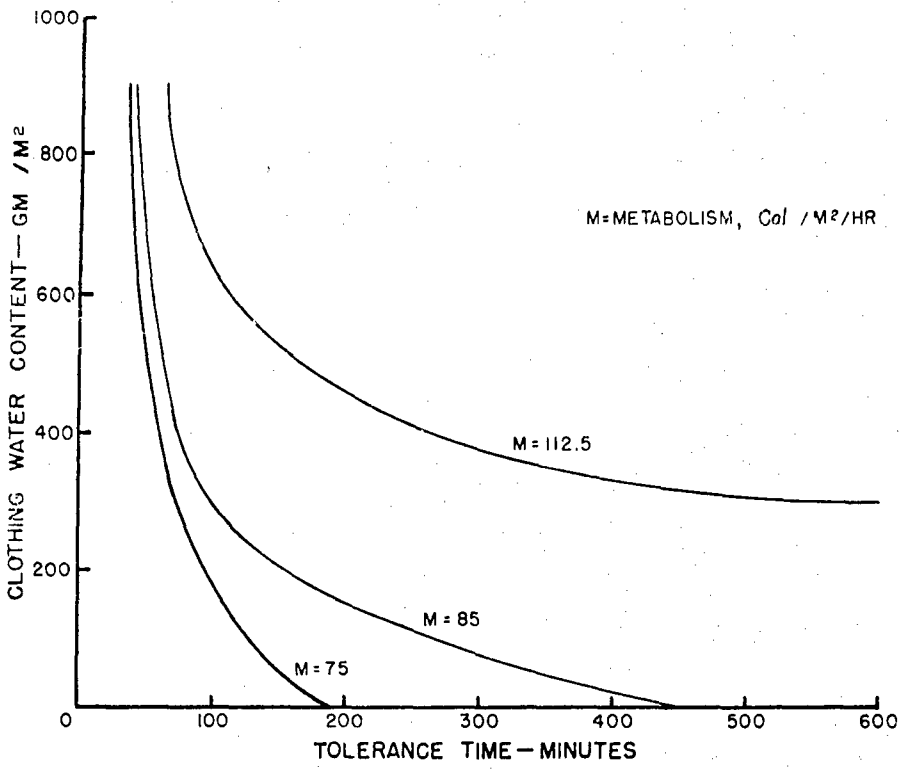


FIGURE 17 — PREDICTED TOLERANCE TIME IN WATER AT 0°C AS A FUNCTION OF CLOTHING WATER CONTENT

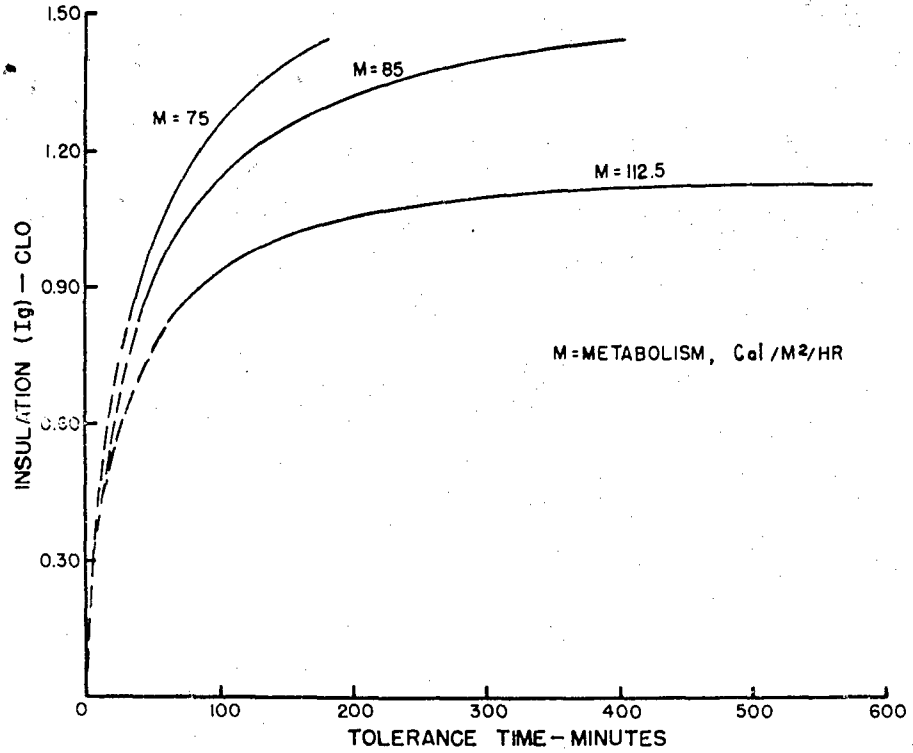


FIGURE 18 — PREDICTED TOLERANCE TIME IN WATER AT 0°C AS A FUNCTION OF INSULATION (Ig)

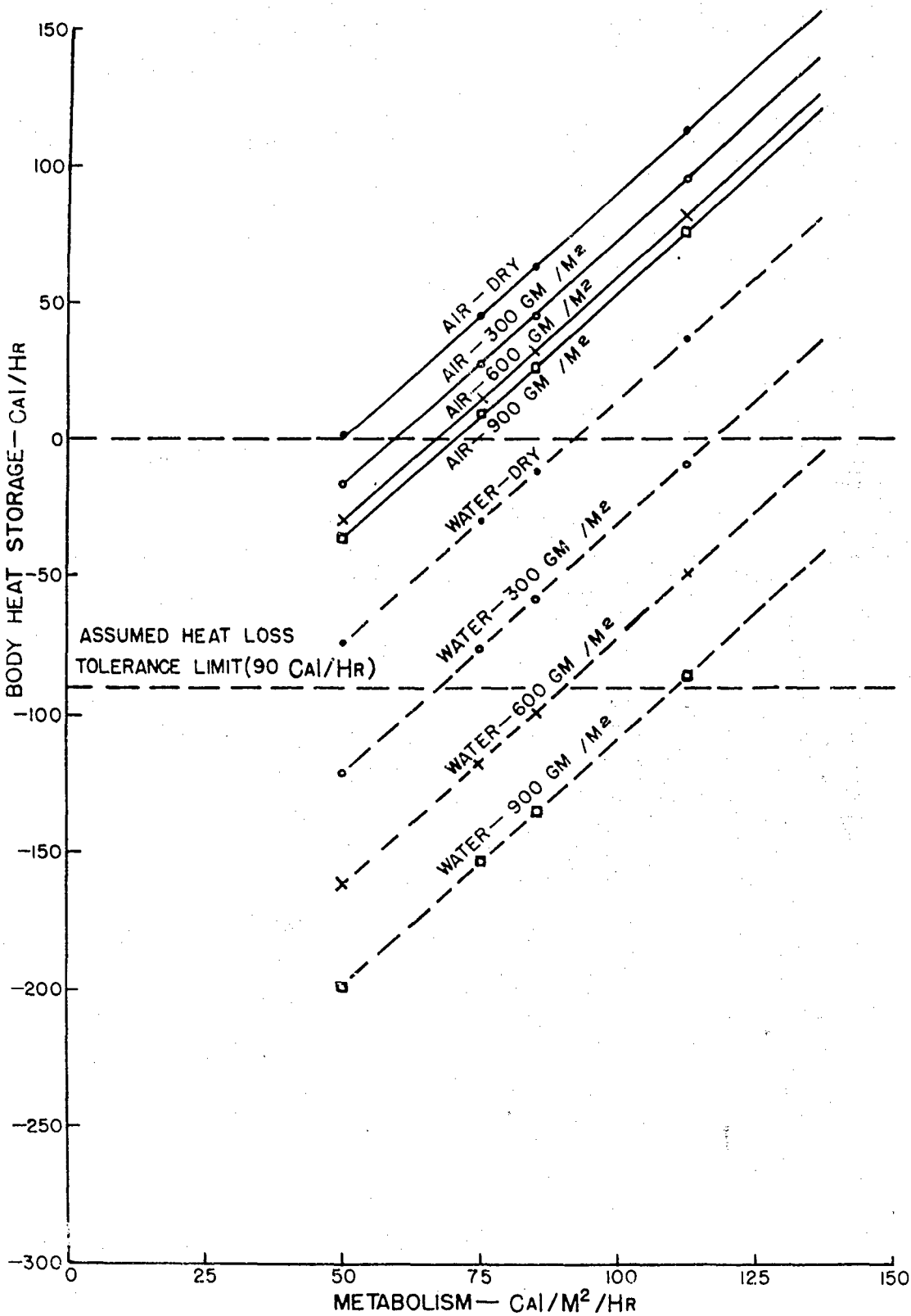
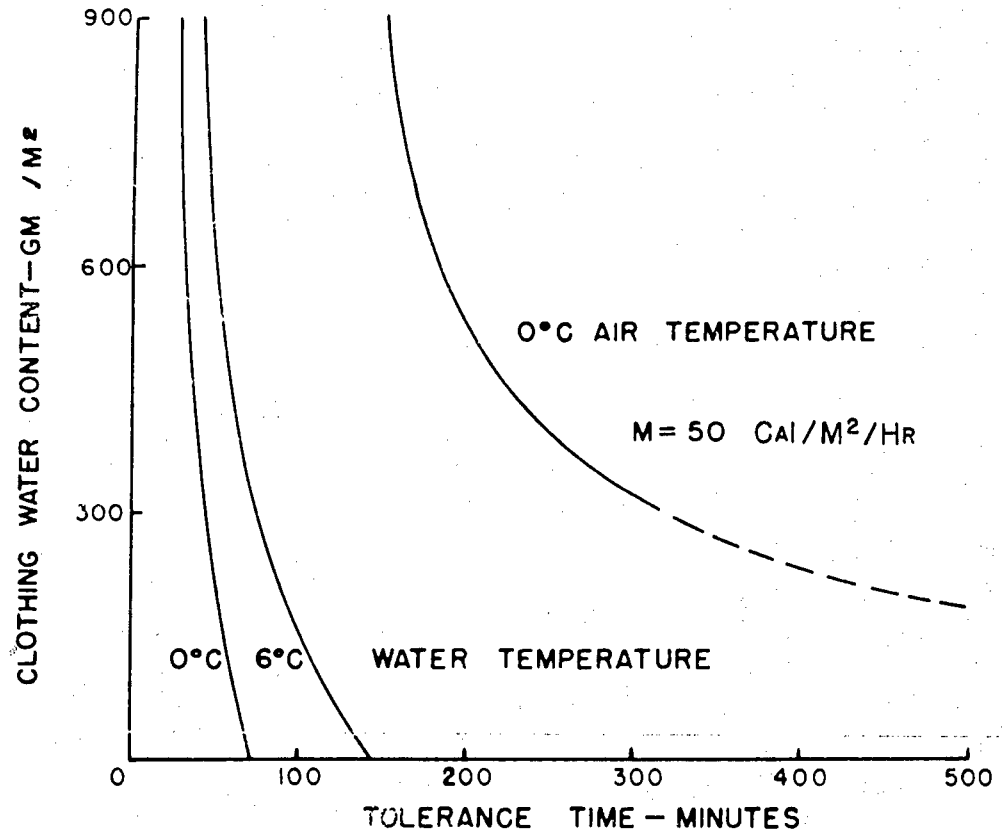


FIGURE 19 — NET BODY HEAT STORAGE IN AIR AND WATER AT 0°C WITH DRY AND WET CLOTHING, AT VARIOUS METABOLIC LEVELS



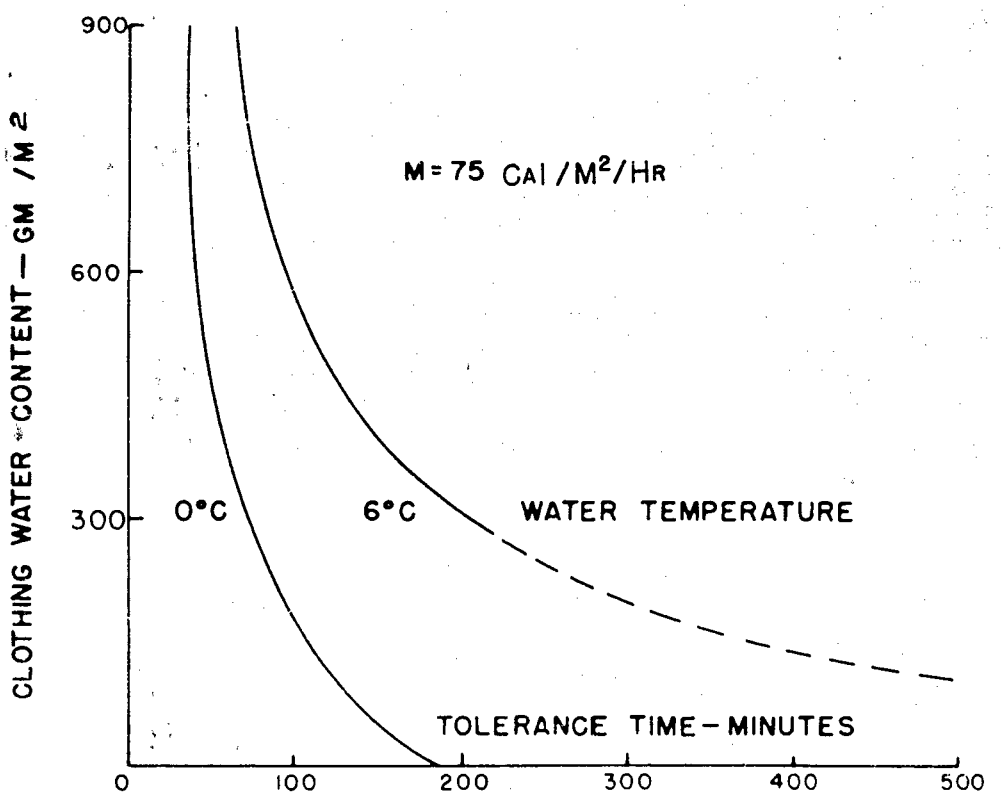


FIGURE 20–PREDICTED TOLERANCE TIME AT VARIOUS WATER AND AIR TEMPERATURES AND METABOLIC LEVELS AS A FUNCTION OF CLOTHING WATER CONTENT

DISCUSSION

The studies of Griffin,[2] Spealman,[9] and Newburgh[6,7,8] demonstrated the serious effects of moisture, either in the form of accumulated sweat, or as water leakage, on clothing insulation. Effective insulation of a clothing item or assembly was reduced to the extent that water or ice replaces the insulating air space. However, in these previous researches the effect of water compression in conjunction with clothing wetness was not considered. In cold water immersion, compression of the clothing by hydrostatic pressure is an important factor. With a man immersed in water to the neck level, approximately 92% of the clothing worn is under some compression load. The results obtained indicate the significant (56.8%) loss of thermal insulation due to water compression. These results have practical implications since they emphasize the need for compression-resistant type clothing during cold water exposures if most effective thermal insulation is to be provided. Several experimental USAF types of compression-resistant insulating liners are now being fabricated and their relative thermal protection property in water will be evaluated. In view of the serious loss of thermal insulation due to immersion in the vertical position, a supine floating position in water has some advantages when considered from the thermal viewpoint.

Previous experience of many investigators under arctic conditions conclusively pointed out the hazard to survival which moisture or sweat accumulation within clothing poses. Except for the work of Griffin,[2] however, little quantitative data is in existence concerning the relationship between clothing thermal insulation (clo) and clothing moisture content. In cold water immersion, maintenance of dry insulation by preventing water leakage and by minimizing accumulation of sweat within the clothing are especially important for survival. Both large (complete clothing assembly) and small wetted areas (socks) were studied, and on a water content per unit surface area basis the observed effects on insulation were similar. This is indicated in the curves of figure 10 and in the percentage profiles of figure 11. Effect of water content on thermal insulation, whether measured in air, or in water where compression loads are present, was generally similar. Variation in the pattern by which the water was added to the clothing did not significantly alter the test results. Quantity of water, rather than its distribution, appears the more significant factor in respect to effect on thermal insulation of clothing. Although small quantities of water (100 gm/m^2 or less) do not critically reduce thermal insulation, the effect of greater clothing water content becomes increasingly serious and at the maximal degree of wetness (900 gm/m^2) effective insulation was reduced to approximately one half the dry value.

Estimations of heat loss in water reported by Aschoff[1] were based on calorimetric measurements of heat loss of the hands only. More recently Molnar[5] compared entire body cooling in air and in water based on data taken after one hour of exposure. These estimates indicate that heat loss from the body in water is only about twice that in air, or only one tenth the amount expected on the basis of water/air conductivity. As this investigator points out, there are, of course, some errors involved in these estimates, but they could not be

great enough to bring heat loss in water to more than three or four times that in air. The greater effective body surface area for heat loss in water, together with the greater specific heat of water, were cited as the chief reasons explaining the estimated heat loss increases in water.

The relative heat losses measured in this study confirm the previously estimated values of Molnar. The manikin dressed in dry clothing lost heat 2.3 times more rapidly in water than in air; with clothing maximally wetted (900 gm/m^2) the rate of heat loss in water increased to 4.0 times the heat loss rate in air (with clothing dry). Cooling of clothed individuals immersed in water, as compared with air, thus increases somewhat if clothing contains an appreciable quantity of water. The measurements of heat loss of the clothed manikin in water and in air were performed under equilibrium conditions (i.e., with a constant temperature gradient between copper manikin skin surface (T_s) and ambient water or air (T_a). In cases involving human cooling in water, vasomotor response and metabolic stimulation due to shivering are of course complicating factors. However, assuming temperature equilibrium conditions, the above measured differences in cooling rates in water and air should be closely approximated.

With the relationship between insulation and clothing water content defined, predictive curves of human tolerance based on an assumed body heat debt (50 Cal/m^2/hr) in water at 0°C are possible. In these calculated tolerance time curves two characteristic events of cold water immersion were considered: (1) the rapid cooling of the skin even with clothed individuals, and (2) the stimulation of metabolism due to shivering. Based on previous results obtained in cold water immersion experiments with human subjects wearing comparable insulation,[4] a mean terminal skin temperature of 24°C was assumed, as well as a 50% increase in metabolic level for exposures of reasonable duration (1-2 hours). These characteristic responses of clothed humans to cold water immersion have, therefore, been included in these predictions of tolerance time. Since both responses are based on experimental data, their inclusion should result in more realistic rescue or survival times than have been previously possible. The rapid fall of skin temperature was nearly always observed; however, wide individual variations as regards onset and severity of shivering occurred and the value used above is a conservative one based on a minimal shivering response. As the prediction curves (figs. 17, 18, 19 and 20) illustrate, metabolic level and dry insulation are both critical factors in determining tolerance time in cold water. The importance of preventing water leakage and maintaining a high metabolic level are clearly indicated. Both are required if tolerance time is to be maximally extended. At any given metabolic level the distinct advantage of maintaining dry insulation, as well as the relative severity of water versus air exposures is graphically presented (fig. 19) for the protective type clothing assembly tested.

The assumption of a body heat debt limit of 50 Cal/m^2/hr is based on measurements obtained in cold air exposures and is also a conservative value. Undoubtedly, some individuals can tolerate larger heat debts safely. However, for purposes of establishing practical and realistic estimations of safe tolerance time for all types of individuals, minimal shivering responses and some clothing water content must be assumed. These factors tend to significantly increase heat loss in water and thus decrease safe tolerance time. In the use

of these predicted tolerance curves, the pre-immersion metabolic level, water content of the insulating clothing, and water temperatue in which immersion occurs must be approximately known or reasonably estimated, before estimations of tolerance or rescue times may be reliably made. If a metabolic level of 75 Cal/m^2/hr is assumed, these results in general confirm the previous estimations[3] of from two to three hours tolerance time in water of 0°C.

CONCLUSIONS

Immersion to the neck level of a clothed individual in water significantly reduces thermal insulation because of hydrostatic compression. This reduction amounting to 57% in the typical Air Force protective clothing assembly measured, emphasizes the need for compression-resistant clothing if optimal cold water immersion protection is to be attained. The addition of measured amounts of water into dry clothing (simulating either sweat and/or water leakage) causes a further loss of thermal insulation if measured in water, and a corresponding loss if measured in air. The effect of adding water in quantities ranging from 100 to 1000 gm/m^2 was similar in terms of percentage insulation loss when water is added to small body areas (feet) or to large clothed areas (trunk, arms, legs). Quantity, rather than distribution, of water appears most significant from a thermal viewpoint. Heat loss in water when measured with a clothed thermal manikin gave values 2.3 to 4.0 times greater than in air, depending upon whether clothing was dry or maximally wetted (1000 gm/m^2). This measured value generally confirms previously calculated values as reported by Molnar. On a basis of a total body heat debt of 50 Cal/m^2/hr, predictive curves for human tolerance in water at 0°C as functions of clothing water content, insulation and metabolic level are presented. In these predicted tolerance times, the factors of rapid skin cooling and metabolic stimulation due to shivering, both characteristic of cold water immersion, have been considered. The calculated curves are based upon previously reported measurements of these factors in clothed human subjects immersed in cold water. Utilized with proper caution, these predictive curves provide more realistic and practical estimations of tolerance time in cold water than has previously been possible. The quantitative significance of dry insulation and high metabolic level in terms of extending tolerance to cold water immersion is emphasized.

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